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Artificial intelligence

Artificial intelligence (**AI**) is intelligence demonstrated by machines, as opposed to the **natural intelligence** displayed by humans or animals. Leading AI textbooks define the field as the study of "intelligent agents": any system that perceives its environment and takes actions that maximize its chance of achieving its goals.[a] Some popular accounts use the term "artificial intelligence" to describe machines that mimic "cognitive" functions that humans associate with the human mind, such as "learning" and "problem solving", however this definition is rejected by major AI researchers.[b]

AI applications include advanced web search engines (i.e. Google), recommendation systems (used by YouTube, Amazon and Netflix), understanding human speech (such as Siri or Alexa), self-driving cars (e.g. Tesla), and competing at the highest level in strategic game systems (such as chess and Go),[2] As machines become increasingly capable, tasks considered to require "intelligence" are often removed from the definition of AI, a phenomenon known as the AI effect.[3] For instance, optical character recognition is frequently excluded from things considered to be AI,[4] having become a routine technology.[5]

Artificial intelligence was founded as an academic discipline in 1956, and in the years since has experienced several waves of optimism,[6][7] followed by disappointment and the loss of funding (known as an "AI winter"),[8][9] followed by new approaches, success and renewed funding.[7][10] AI research has tried and discarded many different approaches during its lifetime, including simulating the brain, modeling human problem solving, formal logic, large databases of knowledge and imitating animal behavior. In the first decades of the 21st century, highly mathematical statistical machine learning has dominated the field, and this technique has proved highly successful, helping to solve many challenging problems throughout industry and academia.[11][10]

The various sub-fields of AI research are centered around particular goals and the use of particular tools. The traditional goals of AI research include reasoning, knowledge representation, planning, learning, natural language processing, perception and the ability to move and manipulate objects.[c] General intelligence (the ability to solve an arbitrary problem) is among the field's long-term goals.[12] To solve these problems, AI researchers use versions of search and mathematical optimization, formal logic, artificial neural networks, and methods based on statistics, probability and economics. AI also draws upon computer science, psychology, linguistics, philosophy, and many other fields.

The field was founded on the assumption that human intelligence "can be so precisely described that a machine can be made to simulate it".[d] This raises philosophical arguments about the mind and the ethics of creating artificial beings endowed with human-like intelligence. These issues have been explored by myth, fiction and philosophy since antiquity.[14] Science fiction and futurology have also suggested that, with its enormous potential and power, AI may become an existential risk to humanity.[15][16]

Contents

History

Precursors

Artificial beings with intelligence appeared as storytelling devices in antiquity,[17] and have been common in fiction, as in Mary Shelley's *Frankenstein* or Karel Čapek's *R.U.R.*[18] These characters and their fates raised many of the same issues now discussed in the ethics of artificial intelligence.[19]


Silver didrachma from Crete depicting Talos, an ancient mythical automaton with artificial intelligence

The study of mechanical or "formal" reasoning began with philosophers and mathematicians in antiquity. The study of mathematical logic led directly to Alan Turing's theory of computation, which suggested that a machine, by shuffling symbols as simple as "0" and "1", could simulate any conceivable act of mathematical deduction. This insight, that digital computers can simulate any process of formal reasoning, is known as the Church–Turing thesis.[20]

Cybernetics and brain simulation

The Church-Turing thesis, along with concurrent discoveries in neurobiology, information theory and cybernetics, led researchers to consider the possibility of building an electronic brain.[21] The first work that is now generally recognized as AI was McCullouch and Pitts' 1943 formal design for Turing-complete "artificial neurons".[22] By 1960, this approach was largely abandoned, although elements of it would be revived in the 1980s.

Symbolic AI

When access to digital computers became possible in the mid-1950s, AI research began to explore the possibility that human intelligence could be reduced to symbol manipulation. Approaches based on cybernetics or artificial neural networks were abandoned or pushed into the background.

The field of AI research was born at a workshop at Dartmouth College in 1956.[e][25] The attendees became the founders and leaders of AI research.[f] They and their students produced programs that the press described as "astonishing":[g] computers were learning checkers strategies, solving word problems in algebra, proving logical theorems and speaking English.[h][27] By the middle of the 1960s, research in the U.S. was heavily funded by the Department of Defense[28] and laboratories had been established around the world.[29]

Researchers in the 1960s and the 1970s were convinced that symbolic approaches would eventually succeed in creating a machine with artificial general intelligence and considered this the goal of their field.[30] Herbert Simon predicted, "machines will be capable, within twenty years, of doing any work a man can do".[31] Marvin Minsky agreed, writing, "within a generation ... the problem of creating 'artificial intelligence' will substantially be solved".[32]

They failed to recognize the difficulty of some of the remaining tasks. Progress slowed and in 1974, in response to the criticism of Sir James Lighthill[33] and ongoing pressure from the US Congress to fund more productive projects, both the U.S. and British governments cut off exploratory research in AI. The next few years would later be called an "AI winter", a period when obtaining funding for AI projects was difficult. [8]

In the early 1980s, AI research was revived by the commercial success of expert systems,[34] a form of AI program that simulated the knowledge and analytical skills of human experts. By 1985, the market for AI had reached over a billion dollars. At the same time, Japan's fifth generation computer project inspired the

U.S and British governments to restore funding for academic research.[7] However, beginning with the collapse of the Lisp Machine market in 1987, AI once again fell into disrepute, and a second, longer-lasting winter began.[9]

Early subsymbolic

Many researchers began to doubt that the symbolic approach would be able to imitate all the processes of human cognition, especially perception, robotics, learning and pattern recognition. A number of researchers began to look into "sub-symbolic" approaches to specific AI problems.[35] Robotics researchers, such as Rodney Brooks, rejected symbolic AI and focused on the basic engineering problems that would allow robots to move, survive, and learn their environment.[i] Interest in neural networks and "connectionism" was revived by Geoffrey Hinton, David Rumelhart and others in the middle of the 1980s.[40] Soft computing tools were developed in the 80s, such as neural networks, fuzzy systems, Grey system theory, evolutionary computation and many tools drawn from statistics or mathematical optimization.

Statistical AI

AI gradually restored its reputation in the late 1990s and early 21st century by finding specific solutions to specific problems. The narrow focus allowed researchers to produce verifiable results, exploit more mathematical methods, and collaborate with other fields (such as statistics, economics and mathematics).[41] By 2000, solutions developed by AI researchers were being widely used, although in the 1990s they were rarely described as "artificial intelligence".[11]

Faster computers, algorithmic improvements, and access to large amounts of data enabled advances in machine learning and perception; data-hungry deep learning methods started to dominate accuracy benchmarks around 2012.[42] According to Bloomberg's Jack Clark, 2015 was a landmark year for artificial intelligence, with the number of software projects that use AI within Google increased from a "sporadic usage" in 2012 to more than 2,700 projects. Clark also presents factual data indicating the improvements of AI since 2012 supported by lower error rates in image processing tasks.[j] He attributes this to an increase in affordable neural networks, due to a rise in cloud computing infrastructure and to an increase in research tools and datasets.[10] In a 2017 survey, one in five companies reported they had "incorporated AI in some offerings or processes".[43]

Artificial general intelligence research

Bernard Goetz and others became concerned that AI was no longer pursuing the original goal of creating versatile, fully intelligent machines. Statistical AI is overwhelmingly used to solve specific problems, even highly successful techniques such as deep learning. They founded the subfield artificial general intelligence (or "AGI"), which had several well-funded institutions by the 2010s.[12]

Research trends in artificial intelligence

Cross-cutting technologies accounted for 18% of global scientific output in 2019, led by AI and robotics, the top of ten sub-fields of cross-cutting technologies by number of publications.[44] These data stem from a bibliometric analysis of scientific publications represented in the Scopus database, produced over 2011 to 2019. Between 2015 and 2019, the shares of China (20.1% in 2019), the EU (25.2%) and USA (10.8%) in AI and robotics receded as developing countries boosted their own output in this field.[44] Among countries with at least 500 publications on AI and robotics over 2012 to 2019, Ecuador showed the fastest growth rate.[44] Ecuadorian scientists produced 248 publications in this field between 2012 and 2015 and 2,208 publications between 2016 and 2019.[44]

Goals

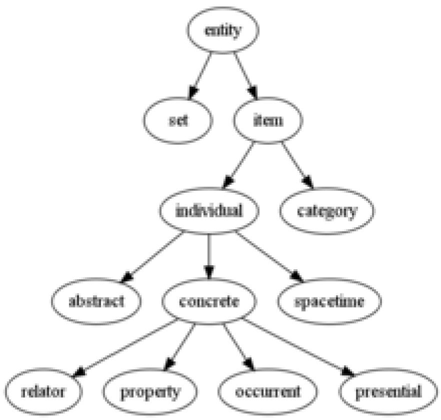
The general problem of simulating (or creating) intelligence has been broken down into sub-problems. These consist of particular traits or capabilities that researchers expect an intelligent system to display. The traits described below have received the most attention.[c]

Reasoning, problem solving

Early researchers developed algorithms that imitated step-by-step reasoning that humans use when they solve puzzles or make logical deductions.[45] By the late 1980s and 1990s, AI research had developed methods for dealing with uncertain or incomplete information, employing concepts from probability and economics.[46]

Many of these algorithms proved to be insufficient for solving large reasoning problems because they experienced a "combinatorial explosion": they became exponentially slower as the problems grew larger.[47] Even humans rarely use the step-by-step deduction that early AI research could model. They solve most of their problems using fast, intuitive judgments.[48]

Knowledge representation



An ontology represents knowledge as a set of concepts within a domain and the relationships between those concepts.

Knowledge representation and knowledge engineering[49] allow AI programs to answer questions intelligently and make deductions about real world facts.

A representation of "what exists" is an ontology: the set of objects, relations, concepts, and properties formally described so that software agents can interpret them.[50] The most general ontologies are called upper ontologies, which attempt to provide a foundation for all other knowledge and act as mediators between domain ontologies that cover specific knowledge about a particular knowledge domain (field of interest or area of concern). A truly intelligent program would also need access to commonsense knowledge; the set of facts that an average person knows. The semantics of an ontology is typically represented in a description logic, such as the Web Ontology Language.[51]

AI research has developed tools to represent specific domains, such as: objects, properties, categories and relations between objects;[51] situations, events, states and time;[52] causes and effects;[53] knowledge about knowledge (what we know about what other people know);[54] default reasoning (things that humans assume are true until they are told differently and will remain true even when other facts are changing);[55] as well as other domains. Among the most difficult problems in AI are: the breadth of commonsense knowledge (the number of atomic facts that the average person knows is enormous);[56] and the sub-symbolic form of most commonsense knowledge (much of what people know is not represented as "facts" or "statements" that they could express verbally).[48]

Formal knowledge representations are used in content-based indexing and retrieval,[57] scene interpretation,[58] clinical decision support,[59] knowledge discovery (mining "interesting" and actionable inferences from large databases),[60] and other areas.[61]

Planning

An intelligent agent that can plan makes a representation of the state of the world, makes predictions about how their actions will change it and makes choices that maximize the utility (or "value") of the available choices.[62] In classical planning problems, the agent can assume that it is the only system acting in the world, allowing the agent to be certain of the consequences of its actions.[63] However, if the agent is not the only actor, then it requires that the agent reason under uncertainty, and continuously re-assess its environment and adapt.[64] Multi-agent planning uses the cooperation and competition of many agents to achieve a given goal. Emergent behavior such as this is used by evolutionary algorithms and swarm intelligence.[65]

Learning

For this project the AI had to learn the typical patterns in the colors and brushstrokes of Renaissance painter Raphael. The portrait shows the face of the actress Ornella Muti, "painted" by AI in the style of Raphael.

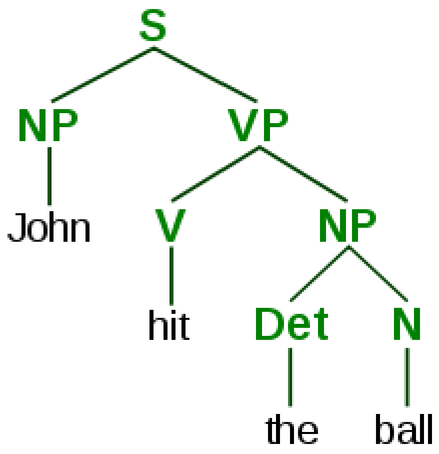
Machine learning (ML), a fundamental concept of AI research since the field's inception,[k] is the study of computer algorithms that improve automatically through experience.[l]

Unsupervised learning finds patterns in a stream of input. Supervised learning requires a human to label the input data first, and comes in two main varieties: classification and numerical regression. Classification is used to determine what category something belongs in -- the program sees a number of examples of things from several categories and will learn to classify new inputs. Regression is the attempt to produce a function that describes the relationship between inputs and outputs and predicts how the outputs should change as the inputs change. Both classifiers and regression learners can be viewed as "function approximators" trying to learn an unknown (possibly implicit) function; for example, a spam classifier can be viewed as learning a function that maps from the text of an email to one of two categories, "spam" or "not spam".[69] In reinforcement learning the agent is rewarded for good responses and punished for bad ones. The agent classifies its responses to form a strategy for operating in its problem space.[70]

Computational learning theory can assess learners by computational complexity, by sample complexity (how much data is required), or by other notions of optimization.[71]

Natural language processing

Natural language processing (NLP)[72] allows machines to read and understand human language. A sufficiently powerful natural language processing system would enable natural-language user interfaces and the acquisition of knowledge directly from human-written sources, such as newswire texts. Some straightforward applications of NLP include information retrieval, question answering and machine translation.[73]



A parse tree represents the syntactic structure of a sentence according to some formal grammar.

Symbolic AI used formal syntax to translate the deep structure of sentences into logic. This failed to produce useful applications, due to the intractability of logic[47] and the breadth of commonsense knowledge.[56] Modern statistical techniques include co-occurrence frequencies (how often one word appears near another), "Keyword spotting" (searching for a particular word to retrieve information), transformer-based deep learning (which finds patterns in text), and others.[74] They have achieved acceptable accuracy at the page or paragraph level, and, by 2019, could generate coherent text.[75]

Perception


Feature detection (pictured: edge detection) helps AI compose informative abstract structures out of raw data.

Machine perception[76] is the ability to use input from sensors (such as cameras, microphones, wireless signals, and active lidar, sonar, radar, and tactile sensors) to deduce aspects of the world. Applications include speech recognition,[77] facial recognition, and object recognition.[78] Computer vision is the ability to analyze visual input.[79]

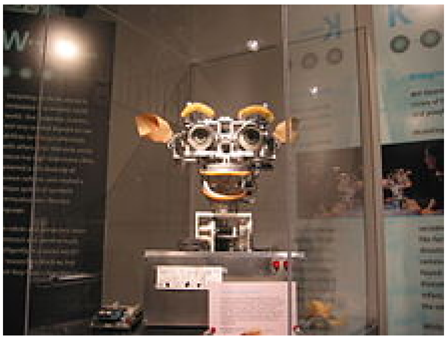
Motion and manipulation

AI is heavily used in robotics.[80] Localization is how a robot knows its location and map its environment. When given a small, static, and visible environment, this is easy; however, dynamic environments, such as (in endoscopy) the interior of a patient's breathing body, pose a greater challenge.[81] Motion planning is the process of breaking down a movement task into "primitives" such as individual joint movements. Such movement often involves compliant motion, a process where movement requires maintaining physical contact with an object. Robots can learn from experience how to move efficiently despite the presence of friction and gear slippage.[82]

Social intelligence

Affective computing is an interdisciplinary umbrella that comprises systems which recognize, interpret, process, or simulate human feeling, emotion and mood. For example, some virtual assistants are programmed to speak conversationally or even to banter humorously; it makes them appear more sensitive to the emotional dynamics of human interaction, or to otherwise facilitate human–computer interaction.[84] However, this tends to give naïve users an unrealistic conception of how intelligent existing computer agents actually are.[85] Moderate successes related to affective computing include textual sentiment analysis and, more recently, multimodal sentiment analysis), wherein AI classifies the affects displayed by a videotaped subject.[86]

General intelligence



Kismet, a robot with rudimentary social skills[83]

General intelligence is the ability to take on any arbitrary problem. Current AI research has, for the most part, only produced programs that can solve exactly one problem. Many researchers predict that such "narrow AI" work in different individual domains will eventually be incorporated into a machine with general intelligence, combining most of the narrow skills mentioned in this article and at some point even exceeding human ability in most or all these areas. The sub-field of artificial general intelligence (or "AGI") studies general intelligence exclusively.[12]

Tools

Applications

AI is relevant to any intellectual task.[87] Modern artificial intelligence techniques are pervasive and are too numerous to list here.[88] Frequently, when a technique reaches mainstream use, it is no longer considered artificial intelligence; this phenomenon is described as the AI effect.[89]

In the 2010s, AI applications were at the heart of the most commercially successful areas of computing, including: search engines (such as Google Search), targeting online advertisements,[90] recommendation systems (such as offered by Netflix or Amazon), driving internet traffic,[91][92] virtual assistants (such as Siri), autonomous vehicles (such as drones and self-driving cars), facial recognition in photographs, and spam filtering.

There are also hundreds of successful AI applications used to solve problems for specific industries or institutions. A few examples are: energy storage,[93] medical diagnosis, military logistics, or supply chain management.

Some high-profile experimental applications demonstrate the capabilities of AI technology, such as: playing games (such as Chess or Go),[2] deepfakes,[94] prediction of judicial decisions,[95] creating art (such as poetry) or proving mathematical theorems.

Numerous applications of varying degrees of complexity have placed AI in the public consciousness, which has raised AI's profile and contributed to research interest. These include:

- Deep Blue became the first computer chess-playing system to beat a reigning world chess champion, Garry Kasparov, on 11 May 1997.
- In 2011, in a *Jeopardy!* quiz show exhibition match, IBM's question answering system, Watson, defeated the two greatest *Jeopardy!* champions, Brad Rutter and Ken Jennings, by a significant margin.
- The Kinect, which provides a 3D body–motion interface for the Xbox 360 and the Xbox One, uses algorithms that emerged from lengthy AI research
- Intelligent personal assistants, such as Siri and Alexa, are able to understand many natural language requests.
- In March 2016, AlphaGo won 4 out of 5 games of Go in a match with Go champion Lee Sedol, becoming the first computer Go-playing system to beat a professional Go player without handicaps. In the 2017 Future of Go Summit, AlphaGo won a three-game match with Ke Jie, who at the time continuously held the world No. 1 ranking for two years. Deep Blue's Murray Campbell called AlphaGo's victory "the end of an era... board games are more or

less done and it's time to move on." This marked the completion of a significant milestone in the development of Artificial Intelligence as Go is a relatively complex game, more so than Chess. AlphaGo was later improved, generalized to other games like chess, with AlphaZero; and MuZero to play many different video games, that were previously handled separately, in addition to board games.

- Other programs handle imperfect-information games; such as for poker at a superhuman level, Pluribus (poker bot) and Cepheus (poker bot). See: General game playing.
- Microsoft developed a Skype system that can automatically translate from one language to another.
- Facebook developed a system that can describe images to blind people.
- By 2020, Natural Language Processing systems such as the enormous GPT-3 (then by far the largest artificial neural network) were matching human performance on pre-existing benchmarks, albeit without the system attaining commonsense understanding of the contents of the benchmarks.
- DeepMind's AlphaFold 2 (2020) demonstrated the ability to determine, in hours rather than months, the 3D structure of a protein. Facial recognition advanced to where, under some circumstances, some systems claim to have a 99% accuracy rate.

Philosophy

Defining artificial intelligence

Thinking vs. acting: the Turing test

Can machines "think"?[m] Alan Turing proposed changing the question from whether a machine "thinks", to "whether or not it is possible for machinery to show intelligent behaviour".[97] The only thing we can see is the behavior of the machine, so it does not matter if the machine is conscious, or has a mind, or whether the intelligence is merely a "simulation" and not "the real thing". He noted that we also don't know these things about other people, but that we extend a "polite convention" that they are actually "thinking". This idea forms the basis of the Turing test.[98]

Acting humanly vs. acting intelligently: intelligent agents

Should artificial intelligence simulate natural intelligence by studying psychology or neurobiology? Or is human biology as irrelevant to AI research as bird biology is to aeronautical engineering?[n]

The intelligent agent paradigm[101] defines intelligent behavior in general, without reference to human beings. An intelligent agent is a system that perceives its environment and takes actions that maximize its chances of success. Any system that has goal-directed behavior can be analyzed as an intelligent agent: something as simple as a thermostat, as complex as a human being, as well as large systems such as firms, biomes or nations. The intelligent agent paradigm became widely accepted during the 1990s, and currently serves as the definition of the field.[a]

The paradigm has other advantages for AI. It provides a reliable and scientific way to test programs; researchers can directly compare or even combine different approaches to isolated problems, by asking which agent is best at maximizing a given "goal function". It also gives them a common language to communicate with other fields — such as mathematical optimization (which is defined in terms of "goals") or economics (which uses the same definition of a "rational agent").[102]

Evaluating approaches to AI

For most of its history, no established unifying theory or paradigm has guided AI research,[o] The unprecedented success of statistical machine learning in the 2010s eclipsed all other approaches (so much so that some sources, especially in the business world, use the term "artificial intelligence" to mean "machine learning with neural networks"). However, the philosophical issues raised in these debates may eventually need to be resolved by future generations of AI researchers.

Symbolic AI and its limits

Should AI use abstract symbolic thought, as people do when they solve difficult puzzles, do mathematics or express legal reasoning? Or should AI simulate the pre-conscious instincts that people use to recognize patterns and make guesses, but may may fall prey to the same kind of inscrutable mistakes that human intuition makes?[104]

Symbolic AI (or "GOFAI")[105] used high level, human readable symbols as tokens in formal systems and wrote algorithms using search and logic. They were highly successful at "intelligent" tasks such as algebra or IQ tests. In the 1960s, Newell and Simon proposed the physical symbol systems hypothesis: "A physical symbol system has the necessary and sufficient means of general intelligent action."[106]

However, the symbolic approach failed dismally on many tasks that humans solve easily, such as learning, recognizing an object or commonsense reasoning. Moravec's paradox is the discovery that high-level "intelligent" tasks were easy for AI, but low level "instinctive" tasks were extremely difficult.[107] Philosopher Hubert Dreyfus had argued since the 1960s that human expertise depends on unconscious instinct rather than conscious symbol manipulation, and on having a "feel" for the situation, rather than explicit symbolic knowledge.[108] Although his arguments had been ridiculed and ignored when they were first presented, eventually AI research came to agree.[p][48]

The issue is not completely resolved, and critics such Noam Chomsky argue continuing research into symbolic AI will still be necessary to attain general intelligence,[110][111] in part because sub-symbolic AI is a move away from explainable AI: it can be difficult or impossible to understand why a modern statistical AI program made a particular decision.

Neat vs. scruffy

Can intelligent behavior be described using simple, elegant principles (such as logic, optimization, or neural networks)? Or does it necessarily require solving a large number of unrelated problems? This question was actively discussed in the 70s and 80s,[112] but in the 1990s mathematical methods and solid scientific standards became the norm, a transition that Russell and Norvig termed "the victory of the neats".[113]

Soft vs. hard computing

Finding a provably correct or optimal solution is intractable for many important problems. [47] Soft computing is a set of techniques, including genetic algorithms, fuzzy logic and neural networks, that are tolerant of imprecision, uncertainty, partial truth and approximation. Soft computing was introduced in the late 80s and most successful AI programs in the 21st century are examples of soft computing with neural networks.

Narrow vs. general AI

Should AI pursue the goals of artificial general intelligence and superintelligence directly? Or is it better off solving as many specific problems as it can and hoping these solutions will lead indirectly to the field's long-term goals?[114][115] General intelligence is difficult to define and difficult to measure, and modern AI has had more verifiable successes by focussing on specific problems with specific solutions.

Machine consciousness, sentience and mind

Can a machine have a mind, consciousness and mental states in the same sense that human beings do? This question considers the internal experiences of the machine, rather than its external behavior. Mainstream AI research considers this question irrelevant, because it does not effect the goals of the field. Stuart Russell and Peter Norvig observe that most AI researchers "don't care about the strong AI hypothesis—as long as the program works, they don't care whether you call it a simulation of intelligence or real intelligence."[116] However, the question has become central to the philosophy of mind. It is also typically the central question at issue in artificial intelligence in fiction.

Consciousness

David Chalmers identified two problems in understanding the mind, which he named the "hard" and "easy" problems of consciousness.[117] The easy problem is understanding how the brain processes signals, makes plans and controls behavior. The hard problem is explaining how this *feels* or why it should feel like anything at all. Human information processing is easy to explain, however human subjective experience is difficult to explain. For example, it is easy to imagine a color blind person who has learned to identify which objects in their field of view are red, but it is not clear what would be required for the person to *know what red looks like*.[118]

Computationalism and functionalism

Computationalism is the position in the philosophy of mind that the human mind is an information processing system and that thinking is a form of computing. Computationalism argues that the relationship between mind and body is similar or identical to the relationship between software and hardware and thus may be a solution to the mind-body problem. This philosophical position was inspired by the work of AI researchers and cognitive scientists in the 1960s and was originally proposed by philosophers Jerry Fodor and Hilary Putnam.[119]

Philosopher John Searle characterized this position as "strong AI": "The appropriately programmed computer with the right inputs and outputs would thereby have a mind in exactly the same sense human beings have minds."[q] Searle counters this assertion with his Chinese room argument, which attempts to show that, even if a machine perfectly simulates human behavior, there is still no reason to suppose it also has a mind.[122]

Robot rights

If a machine has a mind and subjective experience, then it may also have sentience (the ability to feel), and if so, then it could also *suffer*, and thus it would be entitled to certain rights.[123] Any hypothetical robot rights would lie on a spectrum with animal rights and human rights.[124] This issue has been considered in fiction for centuries,[125] and is now being considered by, for example, California's Institute for the Future, however critics argue that the discussion is premature.[126]

Future of AI

Superintelligence

A superintelligence, hyperintelligence, or superhuman intelligence is a hypothetical agent that would possess intelligence far surpassing that of the brightest and most gifted human mind. *Superintelligence* may also refer to the form or degree of intelligence possessed by such an agent.[115]

If research into artificial general intelligence produced sufficiently intelligent software, it might be able to reprogram and improve itself. The improved software would be even better at improving itself, leading to recursive self-improvement.[127] It's intelligence would increase exponentially and could dramatically surpass humans. Science fiction writer Vernor Vinge named this scenario the "singularity".[128] Because it is difficult or impossible to know the limits of intelligence or the capabilities of superintelligent machines, the technological singularity is an occurrence beyond which events are unpredictable or even unfathomable.[129]

Robot designer Hans Moravec, cyberneticist Kevin Warwick, and inventor Ray Kurzweil have predicted that humans and machines will merge in the future into cyborgs that are more capable and powerful than either. This idea, called transhumanism, has roots in Aldous Huxley and Robert Ettinger.[130]

Edward Fredkin argues that "artificial intelligence is the next stage in evolution", an idea first proposed by Samuel Butler's "Darwin among the Machines" as far back as 1863, and expanded upon by George Dyson in his book of the same name in 1998.[131]

Risks

Technological unemployment

In the past technology has tended to increase rather than reduce total employment, but economists acknowledge that "we're in uncharted territory" with AI.[132] A survey of economists showed disagreement about whether the increasing use of robots and AI will cause a substantial increase in long-term unemployment, but they generally agree that it could be a net benefit, if productivity gains are redistributed.[133] Subjective estimates of the risk vary widely; for example, Michael Osborne and Carl Benedikt Frey estimate 47% of U.S. jobs are at "high risk" of potential automation, while an OECD report classifies only 9% of U.S. jobs as "high risk".[r][135]

Unlike previous waves of automation, many middle-class jobs may be eliminated by artificial intelligence; *The Economist* states that "the worry that AI could do to white-collar jobs what steam power did to blue-collar ones during the Industrial Revolution" is "worth taking seriously".[136] Jobs at extreme risk range from paralegals to fast food cooks, while job demand is likely to increase for care-related professions ranging from personal healthcare to the clergy.[137]

Bad actors and weaponized AI

AI provides a number of tools that are particularly useful for authoritarian governments: smart spyware, face recognition and voice recognition allow widespread surveillance; such surveillance allows machine learning to classify potential enemies of the state and can prevent them from hiding; recommendation systems can precisely target propaganda and misinformation for maximum effect; deepfakes aid in producing misinformation; advanced AI can make centralized decision making more competitive with liberal and decentralized systems such as markets.[138]

Terrorists, criminals and rogue states may use other forms of weaponized AI such as advanced digital warfare and lethal autonomous weapons. By 2015, over fifty countries were reported to be researching battlefield robots.[139]

Algorithmic bias

AI programs can become biased after learning from real world data. It is not typically introduced by the system designers, but is learned by the program, and thus the programmers are often unaware that the bias exists.[140] Bias can be inadvertently introduced by the way training data is selected.[141] It can also emerge from correlations: AI is used to classify individuals into groups and then make predictions assuming that the individual will resemble other members of the group. In some cases, this assumption may be unfair.[142] An example of this is COMPAS, a commercial program widely used by U.S. courts to assess the likelihood of a defendant becoming a recidivist. ProPublica claims that the COMPAS-assigned recidivism risk level of black defendants is far more likely to be an overestimate than that of white defendants, despite the fact that the program was not told the races of the defendants.[143] Other examples where algorithmic bias can lead to unfair outcomes are when AI is used for credit rating or hiring.

Existential risk

Superintelligent AI may be able to improve itself to the point that humans could not control it. This could, as physicist Stephen Hawking puts it, "spell the end of the human race".[144] Philosopher Nick Bostrom argues that sufficiently intelligent AI, if it chooses actions based on achieving some goal, will exhibit convergent behavior such as acquiring resources or protecting itself from being shut down. If this AI's goals do not fully reflect humanity's, it might need to harm humanity in order to acquire more resources or prevent itself from being shut down, ultimately to better achieve its goal. He concludes that AI poses a risk to mankind, however humble or "friendly" its stated goals might be.[145] Political scientist Charles T. Rubin argues that "any sufficiently advanced benevolence may be indistinguishable from malevolence." Humans should not assume machines or robots would treat us favorably because there is no *a priori* reason to believe that they would share our system of morality.[146]

The opinion of experts and industry insiders is mixed, with sizable fractions both concerned and unconcerned by risk from eventual superhumanly-capable AI.[147] Stephen Hawking, Microsoft founder Bill Gates, history professor Yuval Noah Harari, and SpaceX founder Elon Musk have all expressed serious misgivings about the future of AI.[148] Prominent tech titans including Peter Thiel (Amazon Web Services) and Musk have committed more than $1 billion to nonprofit companies that champion responsible AI development, such as OpenAI and the Future of Life Institute.[149] Mark Hurd (CEO, Oracle) and Mark Zuckerberg (CEO, Facebook), believe that artificial intelligence is helpful in its current form and will continue to assist humans.[150] Other experts argue is that the risks are far enough in the future to not be worth researching, or that humans will be valuable from the perspective of an superintelligent machine.[151] Rodney Brooks, in particular, believes that "malevolent" AI is still centuries away.[s]

Ethical machines

Friendly AI are machines that have been designed from the beginning to minimize risks and to make choices that benefit humans. Eliezer Yudkowsky, who coined the term, argues that developing friendly AI should be a higher research priority: it may require a large investment and it must be completed before AI becomes an existential risk.[153]

Machines with intelligence have the potential to use their intelligence to make ethical decisions. The field of machine ethics provides machines with ethical principles and procedures for resolving ethical dilemmas.[154] Machine ethics is also called machine morality, computational ethics or computational morality.[154] and was founded at an AAAI symposium in 2005.[155]

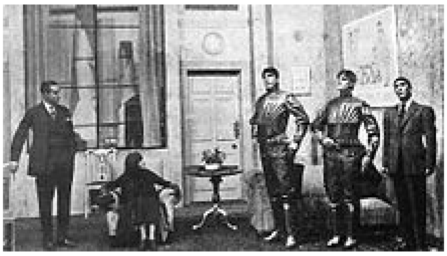
Others approaches include Wendell Wallach's "artificial moral agents"[156] and Stuart J. Russell's three principles for developing provably beneficial machines.[157]

Regulation

The regulation of artificial intelligence is the development of public sector policies and laws for promoting and regulating artificial intelligence (AI); it is therefore related to the broader regulation of algorithms.[158] The regulatory and policy landscape for AI is an emerging issue in jurisdictions globally.[159] Between 2016 and 2020, more than 30 countries adopted dedicated strategies for AI.[44] Most EU member states had released national AI strategies, as had Canada, China, India, Japan, Mauritius, the Russian Federation, Saudi Arabia, United Arab Emirates, USA and Viet Nam. Others were in the process of elaborating their own AI strategy, including Bangladesh, Malaysia and Tunisia.[44] The Global Partnership on Artificial Intelligence was launched in June 2020, stating a need for AI to be developed in accordance with human rights and democratic values, to ensure public confidence and trust in the technology.[44]

In fiction

Thought-capable artificial beings appeared as storytelling devices since antiquity,[17] and have been a persistent theme in science fiction.[19]



The word "robot" itself was coined by Karel Čapek in his 1921 play *R.U.R.*, the title standing for "Rossum's Universal Robots"

A common trope in these works began with Mary Shelley's *Frankenstein*, where a human creation becomes a threat to its masters. This includes such works as Arthur C. Clarke's and Stanley Kubrick's *2001: A Space Odyssey* (both 1968), with HAL 9000, the murderous computer in charge of the *Discovery One* spaceship, as well as *The Terminator* (1984) and *The Matrix* (1999). In contrast, the rare loyal robots such as Gort from *The Day the Earth Stood Still* (1951) and Bishop from *Aliens* (1986) are less prominent in popular culture.[160]

Isaac Asimov introduced the Three Laws of Robotics in many books and stories, most notably the "Multivac" series about a super-intelligent computer of the same name. Asimov's laws are often brought up during lay discussions of machine ethics;[161] while almost all artificial intelligence researchers are familiar with Asimov's laws through popular culture, they generally consider the laws useless for many reasons, one of which is their ambiguity.[162]

Transhumanism (the merging of humans and machines) is explored in the manga *Ghost in the Shell* and the science-fiction series *Dune*.

Several works use AI to force us to confront the fundamental question of what makes us human, showing us artificial beings that have the ability to feel, and thus to suffer. This appears in Karel Čapek's *R.U.R.*, the films *A.I. Artificial Intelligence* and *Ex Machina*, as well as the novel *Do Androids Dream of Electric Sheep?*, by Philip K. Dick. Dick considers the idea that our understanding of human subjectivity is altered by technology created with artificial intelligence.[163]

See also

- *A.I. Rising*
- AI control problem
- Artificial intelligence arms race
- Artificial general intelligence
- Behavior selection algorithm
- Business process automation
- Case-based reasoning
- Citizen Science
- Emergent algorithm
- Female gendering of AI technologies
- Glossary of artificial intelligence
- Robotic process automation
- Synthetic intelligence
- Universal basic income
- Weak AI

Explanatory notes

a. Definition of AI as the study of intelligent agents, drawn from the leading AI textbooks.
   - Poole, Mackworth & Goebel (1998, p. 1 (http://people.cs.ubc.ca/~poole/ci/ch1.pdf)), which provides the version that is used in this article. These authors use the term "computational intelligence" as a synonym for artificial intelligence.
   - Russell & Norvig (2003, p. 55) (who prefer the term "rational agent") and write "The whole-agent view is now widely accepted in the field".
   - Nilsson (1998)
   - Legg & Hutter (2007)

b. Stuart Russell and Peter Norvig characterize this definition as "thinking humanly" and reject it in favor of "acting rationally".[1]

c. This list of intelligent traits is based on the topics covered by the major AI textbooks, including: Russell & Norvig (2003), Luger & Stubblefield (2004), Poole, Mackworth & Goebel (1998) and Nilsson (1998)

d. This statement comes from the proposal for the Dartmouth workshop of 1956, which reads: "Every aspect of learning or any other feature of intelligence can be so precisely described that a machine can be made to simulate it."[13]

e. Daniel Crevier wrote "the conference is generally recognized as the official birthdate of the new science."[23] Russell and Norvifg call the conference "the birth of artificial intelligence."[24]

f. Russell and Norvig wrote "for the next 20 years the field would be dominated by these people and their students."[24]

g. Russell and Norvig wrote "it was astonishing whenever a computer did anything kind of smartish".[26]

h. The programs described are Arthur Samuel's checkers program for the IBM 701, Daniel Bobrow's STUDENT, Newell and Simon's Logic Theorist and Terry Winograd's SHRDLU.

i. Embodied approaches to AI[36] were championed by Hans Moravec[37] and Rodney Brooks[38] and went by many names: Nouvelle AI,[38] Developmental robotics,[39] situated AI, behavior-based AI as well as others. A similar movement in cognitive science was the embodied mind thesis.

j. Clark wrote: "After a half-decade of quiet breakthroughs in artificial intelligence, 2015 has been a landmark year. Computers are smarter and learning faster than ever."[10]

k. Alan Turing discussed the centrality of learning as early as 1950, in his classic paper "Computing Machinery and Intelligence".[66] In 1956, at the original Dartmouth AI summer conference, Ray Solomonoff wrote a report on unsupervised probabilistic machine learning: "An Inductive Inference Machine".[67]

l. This is a form of Tom Mitchell's widely quoted definition of machine learning: "A computer program is set to learn from an experience *E* with respect to some task *T* and some performance measure *P* if its performance on *T* as measured by *P* improves with experience *E*."[68]

m. The distinction between "acting" and "thinking" is due to Russell and Norvig.[96]

n. The distinction between "acting humanly" and "acting rationally" is due to Russell and Norvig.[96] Pamela McCorduck wrote in 2004 that there are "two major branches of artificial intelligence: one aimed at producing intelligent behavior regardless of how it was accomplished, and the other aimed at modeling intelligent processes found in nature, particularly human ones."[99] Russel and Norvig come down on the side of "acting rationally" and criticize the Turing test: "Aeronautical engineering texts do not define the goal of their field as 'making machines that fly so exactly like pigeons that they can fool other pigeons.'"[96] AI founder John McCarthy agrees and said in 2006 "Artificial intelligence is not, by definition, simulation of human intelligence".[100]

o. Nils Nilsson wrote in 1983: "Simply put, there is wide disagreement in the field about what AI is all about."[103]

p. Daniel Crevier wrote that "time has proven the accuracy and perceptiveness of some of Dreyfus's comments. Had he formulated them less aggressively, constructive actions they suggested might have been taken much earlier."[109]

q. Searle presented this definition of "Strong AI" in 1999.[120] Searle's original formulation was "The appropriately programmed computer really is a mind, in the sense that computers given the right programs can be literally said to understand and have other cognitive states."[121] Strong AI is defined similarly by Russell and Norvig: "The assertion that machines could possibly act intelligently (or, perhaps better, act *as if* they were intelligent) is called the 'weak AI' hypothesis by philosophers, and the assertion that machines that do so are actually thinking (as opposed to simulating thinking) is called the 'strong AI' hypothesis."[116]

r. See table 4; 9% is both the OECD average and the US average.[134]

s. Rodney Brooks writes, "I think it is a mistake to be worrying about us developing malevolent AI anytime in the next few hundred years. I think the worry stems from a fundamental error in not distinguishing the difference between the very real recent advances in a particular aspect of AI and the enormity and complexity of building sentient volitional intelligence."[152]

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   - Russell & Norvig (2003, p. 24)
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   - Newquist (1994, pp. 235–248)

8. First AI Winter, Lighthill report, Mansfield Amendment
    - Crevier (1993, pp. 115–117)
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    - Howe (1994)
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    - Newquist (1994, pp. 301–318)
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12. Pennachin & Goertzel (2007); Roberts (2016)
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14. Newquist 1994, pp. 45–53.
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22. Russell & Norvig 2009, p. 16.
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